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The urban material politics of decarbonization in Stockholm, London and San Francisco

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ABSTRACT

This paper examines the implementation of carbon governance initiatives targeting urban buildings and energy infrastructure and uses a material politics approach to evaluate whether these practices are triggering trajectories towards decarbonization. Urban low carbon transitions suggest a substantial re-ordering of urban infrastructure. However, there is a critical need to engage with the material implications of low carbon practices since research so far has painted a picture of incremental ambitions struggling in implementation. This paper interrogates how carbon governance is implemented through urban buildings and energy systems, and the implications for urban decarbonization, by drawing on three urban case studies: Stockholm, London and San Francisco. The analysis draws on interviews with representatives from government, industry, utilities, building owners, and non-governmental organizations who are striving to achieve decarbonization in their cities. Patterns are emerging in what is being made to matter politically through the translation of carbon governance into building-energy infrastructure. In particular, the paper finds that (1) a short-term decision making timeline encourages action that incrementally reduces greenhouse gas emissions without fundamentally overcoming carbon lock-in, (2) actors are harnessing exceptional urban space to overcome the tyranny of cost-effectiveness in maintaining fossil fuel entrenchment (with concerning implications for justice and uneven development), (3) there is a pattern of individualization of responsibility for decarbonization, and (4) material politics are limiting the application of low carbon retrofits for the existing built form. Overall, this paper examines the implementation of urban carbon governance while encompassing the messy, materially embedded, and contested nature of infrastructure transformations.

1. Introduction

Urban decarbonization requires sweeping transformation to not only urban political and institutional systems, but also the material infrastructures supporting urban life (Bulkeley et al., 2011). The enormous scope of the challenge and opportunity for urban low carbon transition is alternately staggering and galvanizing. Despite widespread and growing adoption of local goals to reduce greenhouse gas emissions, however, urban climate change mitigation action has taken a piecemeal rather than systemic approach (Betsill and Bulkeley, 2007; Bulkeley and Betsill, 2013; Reckien et al., 2014; Romero-Lankao, 2012). Furthermore, actors are explicitly experimenting with low-carbon practices that are uncertain both in terms of successful implementation and actual impact on urban greenhouse gas emissions (Castán Broto and Bulkeley, 2013). Some municipal governments have even started to aim for what they call "deep decarbonization" (Carbon Neutral Cities Alliance, 2015), which specifically targets urban transformation. Urban climate response is also multi-scalar involving diverse actors beyond the local government (Bulkeley and Betsill, 2013; Emelianoff, 2014; Peng and Bai, 2018). While there is a great deal of urban decarbonization activity underway, it is not clear what all of this activity might amount to when it comes to re-making the socio-material fabric of urban areas since action has been incremental, experimental and multi-scalar. This paper engages with the material implications of low carbon practices in cities to offer new insights into whether and how decarbonization efforts are reconfiguring urban buildings and energy infrastructure (Bulkeley et al., 2015; Hodson et al., 2016; Rutherford, 2014). Urban actors are governing carbon in many ways, but buildings are a substantial target for low carbon action and therefore offer a useful entry point into processes of urban decarbonization (Lovell, 2007; Castán Broto and Bulkeley, 2013; Edwards and Bulkeley, 2017).

The aim of this paper is to interrogate how carbon governance is accomplished through urban buildings and energy systems, and the implications for urban decarbonization trajectories, by drawing on three urban case studies: Stockholm, London and San Francisco. To do so, I delve into the material politics of implemented carbon governance

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efforts in cities. I focus on buildings and energy as an interconnected urban infrastructure to understand decarbonization practices. This approach allows me to evaluate whether carbon governance is triggering urban decarbonization, while still encompassing the messy, materially embedded, and contested nature of infrastructure transformations.

This paper examines the slice of urban carbon governance purportedly aiming for transformative decarbonization to provide a novel deepening of our understanding of urban carbon governance. Decarbonization is the reversal of the entrenchment of fossil-fuel energy systems that has resulted from the co-evolution of technological and institutional systems in industrial economies or "carbon lock-in" (Unruh, 2000). One way to understand these transformations is to use a material politics approach to analyze how the city is reconfigured as carbon governance unfolds and the politics of assembling together particular human and non-human elements, but not others (Bulkeley et al., 2016; Rutherford, 2018). This paper uses multiple cities in order to learn through comparison, which complements work in this vein that has largely focused on a tracing the material politics of energy transition interventions within a city (Bulkeley et al., 2016; Rutherford, 2014; Silver, 2017).

More specifically, I examine the patterns emerging through decarbonization practices and use a material politics approach to analyze which aspects of urban materiality come to matter as carbon governance is translated into building-energy infrastructure. There is variation in what is made to matter since carbon management is an idea that can be variously deployed to make different things into problems and solutions. I argue that emerging patterns in urban decarbonization practices carry implications for whether or not cities are on trajectories toward decarbonization. In particular, I find that: a short-term decision making timeline encourages action that incrementally reduces greenhouse gas emissions without fundamentally overcoming carbon lock-in; new urban space is moving toward decarbonization, especially when actors harness exceptional urban space to overcome the tyranny of cost-effectiveness in maintaining fossil fuel entrenchment, but this introduces concerning implications for justice and uneven development; there is a pattern of individualization of responsibility for decarbonization that is limiting the potential scope of urban transformation; and material politics are limiting the application of low carbon retrofits for the existing built form.

2. Material politics of urban infrastructure

In order to examine the re-ordering of the city as low carbon transitions unfold, one can pay greater attention to the material politics of urban infrastructure. Work in this area sees urban infrastructure as dynamic, contested, and socio-political as much as technical (Hodson and Marvin, 2009; Kaika and Swyngedouw, 2000; McFarlane and Rutherford, 2008; Monstadt, 2009; Rutherford and Coutard, 2014). This is related to an interest in materiality – a more-than-human approach (Whatmore, 2006) – that has revived more broadly across geography. Important here is that materials are not a background on which human controversies play out. Decarbonization cannot be rolled out through an obliging set of technologies, policies and practices. Instead, politics is wrapped up with materials in a diverse range of socio-material assemblages. The actualisation of low carbon transitions means intervening in these assemblages towards particular ends.

A material politics approach to urban low carbon transition considers the ways in which urban politics and materialities come to matter as transitions unfold (Bulkeley et al., 2016; Rutherford, 2014). Drawing on Barry's work on the "material politics" of pipelines (Barry, 2013), recent work has used this approach to examine urban energy transitions in response to an overemphasis on policy representations in climate governance literature (Rutherford, 2014; Bulkeley et al., 2016). Using ideas of relational materiality, this approach considers the co-production of materiality through the assemblages of human and non-human elements (Latham et al., 2009). Assembling is an inherently political process and "the political significance of materials is not a given; rather, it is a relational, a practical and a contingent achievement" (Barry, 2013). Some scholars have examined the ways that objects matter politically to consider the relationships between people and objects and the ways that objects are invested with normative and performative powers (Marres, 2012; Meehan et al., 2013; Shaw and Meehan, 2013). Other scholars draw on Foucault to structure their analyses of relational materiality (see Bulkeley et al., 2016), who argued that governing is not just concerned with the social world of actors and institutions, but is made up of a "complex of men and things" (Foucault, 2009). This means that governing involves the assemblage of different elements together and a configuration of power through people and things (McGuirk et al., 2016). Overall, relational approaches to materiality foreground the material, but, importantly, also consider all of the relations the material represents.

I draw on these relational approaches to materiality that consider the ways that human/non-human as well as material/immaterial elements are drawn together and driven apart through the processes of urban circulation. I follow the idea of materiality defined as "a spatio-temporal *process* in which the more tangible, physical stuff of the city is a lively participant" (Latham et al., 2009, p. 62, original emphasis). Rather than arguing that the materiality of places or the agency of objects determines both the path the city will take and the politics of decarbonization, I instead examine the interaction of human and non-human as decarbonization is assembled together. Assembling the elements of carbon governance is "an inherently political process" (Rutherford, 2018) because it necessarily represents particular interests and highlights some snapshots of infrastructure while leaving others in the dark.

In particular, I answer the following questions: As carbon governance is translated into building-energy infrastructure, what is it about urban materiality that comes to matter? What are the implications for urban decarbonization pathways? Following the application of Rutherford (2014), I focus on the relations between people and objects, particularly by considering what is made visible, tangible or durable through practices of ordering, circulation or manipulation. In this way, one can consider how things come to matter by considering how energy transitions are governed, including the acts of formulation, implementation and contestation made visible through artefacts, techniques and practices (Bulkeley et al., 2016). The focus is not on which specific objects come to matter, but, instead, on the ways in which materiality is "present in the connections between things, technologies, people, bodies, signs, texts, etc. with none of these as inherently more material or immaterial than the others" (Rutherford, 2014). Relational lenses, such as time, space or agency, open up opportunities to look beyond urban objects. A material politics approach to analyze the implementation of decarbonization also ensures that the socio-material form that is taken as carbon governance is negotiated and adapted to urban contexts is neither tuned out nor attributed to settled readings of power relations (Bulkeley et al., 2016). Therefore, this approach allows me to maintain the complexity of urban infrastructure transitions while still considering the broader implications of patterns in decarbonization practice that affect whether or not cities are headed toward decarbonization trajectories.

Scholars interested in infrastructures have tended to focus their analyses on infrastructures other than buildings. Urban political ecology, for example, has often focused on water provision and science and technology studies has tended to focused on large technical systems (Monstadt, 2009). While there has been interest among scholars in urban energy infrastructure, there has been limited work on buildings as infrastructure (with notable exceptions, for example see Edwards and Bulkeley (2017)). There has, however, been research into the various ways that buildings are a focal point for the performance of low carbon cities. In particular, see Lovell's work on zero carbon homes (2007) and Marres' work on eco-homes (2008).

In this paper, I argue buildings and energy are best understood as an

interconnected urban infrastructure since they are spatially and conceptually paired in urban decarbonization practice. The mutual influence of building characteristics and energy in decarbonization can be illustrated through two examples. First, district energy systems can use low temperature heat sourced from industry (factories) or city services (sewage waste heat recovery), but buildings must be designed in specific ways to be able to effectively make use of this low temperature heat. Second, investments in energy efficiency retrofits are often rationalized as the cheapest form of energy 'supply' as opposed to constructing new energy generation facilities to meet demand. In this way, building retrofits conceptually become energy supply. Given these conceptual and spatial pairings, it is more productive to conceptualize the building-energy nexus as an urban infrastructure than as separate sectors in order to draw on approaches that emphasize urban flows and the socio-material co-production of urban materiality. This approach makes it easier to see the ways that carbon governance is socio-materially assembled through low carbon interventions in the urban.

3. Research methods

I focused on carbon governance of buildings related to three urban case studies: Stockholm, London and San Francisco. I chose the cases based on three criteria: international leadership in carbon governance, heterogeneity within that leadership group, and evidence of leadership in building decarbonization. The first criterion was membership in the Carbon Neutral Cities Alliance (CNCA), a transnational municipal climate governance network founded in 2014 by local governments in wealthy, industrialized countries. The network is made up of local governments that are, in their own words, adopting "the most aggressive GHG reduction targets undertaken by any cities across the globe" (Carbon Neutral Cities Alliance, 2015:p.ii). The CNCA has a geographic bias in membership towards North America and Europe (see Table 1), but this limited geographic scope is important to study because, as self-identified pioneers of urban "deep decarbonization" (Carbon Neutral Cities Alliance, 2015), the founding members of the CNCA are defining what it means for a city to become carbon neutral. Second, within the restricted scope of the CNCA, I selected cities that are as different from each other as possible in terms of demographics, climate, urban form and institutional setting (e.g. regulatory strength of municipal government, alignment with national climate policies). The third criterion for case study selection was the presence of urban carbon governance of buildings. Strategies aimed at buildings to both improve energy efficiency and decarbonize energy sources are prevalent, but there are also a number of other situation-specific strategies used by urban actors (Kennedy, Ibrahim, and Hoornweg, 2014). Since the study uses urban carbon governance of buildings as an entry point into urban processes of decarbonization, I looked for the presence of carbon governance of buildings over at least a 5 year time period during documentary analysis, which I assumed was a long enough time period for some implementation to have unfolded.

My use of the case study approach is not intended to be a comparison between the cities to find causal factors. Instead, it is an interpretive approach to theorization of urban decarbonization drawing on data from three urban contexts. This approach draws on a key advantage of comparative studies, which is the opportunity to "generate and modify concepts and theory so that they explain commonalities across cases *despite* contingencies or context" (Baxter, 2010, emphasis in original). I draw on three different urban contexts to generate insight into commonalities in urban carbon governance practices and the implications for decarbonization pathways.

Table 1
Founding members of the carbon neutral cities alliance (USDN, 2015).

Berlin, Germany	Minneapolis MN, USA	Stockholm, Sweden
Boston MA, USA	New York City NY, USA	Sydney, Australia
Boulder CO, USA	Oslo, Norway	Vancouver, Canada
Copenhagen, Denmark	Portland OR, USA	Washington DC, USA
London, United Kingdom	San Francisco CA, USA	Yokohama, Japan
Melbourne, Australia	Seattle WA, USA	

The findings are based on semi-structured interviews, documentary analysis of relevant policy document and reports, and site visits to low carbon building and energy infrastructure. I conducted interviews with 40 representatives from the urban development industry (n = 12), government (n = 18), utilities (n = 2), building owners (n = 2) and non-governmental organizations (n = 6) who were involved in building and energy decarbonization over five week field visits to each case study in 2016–2017. I conducted 11 interviews in Stockholm, 16 interviews in London, and 13 interviews in San Francisco. I interviewed a community of practitioners and policymakers striving to achieve decarbonization in their cities, whom I call decarbonization actors. Their efforts represent a political struggle against entrenched interests embodying pervasive carbon lock-in across social, institutional, technical and economic systems (Bernstein and Hoffmann, 2018). This community's approach to decarbonization is also contested by other groups – such as grassroots organizations who push back on discourses of depoliticization and technocratic solutions – but that is outside the scope of this research. The interviews were transcribed and thematically coded. I also conducted 19 building tours and site visits, including in-depth and self-directed tours of buildings ranging from single-family homes to commercial buildings, as well as tours of urban energy infrastructure and site visits to eco-districts and neighbourhoods.

4. Case studies

4.1. Case study: Stockholm

The population of Stockholm is approximately 901,000. The City of Stockholm has a high degree of control over the built environment since it owns about 20% of the buildings in the city (City of Stockholm, 2012) and 70% of the land area. Local government agencies and buildings on city owned land are required to meet energy efficiency targets (see Table 2). Some policies and programs have sought to improve energy efficiency in private buildings in Stockholm, including demonstration projects for multi-family residential buildings, but generally these sectors have been difficult to reach. Stockholm is located in a colder climate and much of the energy load relates to heating. District heating meets 80% of Stockholm heating needs, which has been historically facilitated by the proliferation of communal residential buildings where owners have a share in the whole building (Dzebo and Nykvist, 2017). One key task of carbon governance is fuel switching to non-fossil fuels for district heating, such as biofuels and waste incineration. However, a reliance on incineration places a cap on progress towards decarbonization since about a third of the carbon in Swedish waste is from fossil-fuel sources (e.g. plastics) (Jones et al., 2013). Nonetheless, most city-wide GHG emission reductions to date have been achieved due to this fuel switching. Solar PV installation is also taking place, particularly on municipally owned buildings. Stockholm has also designated the Hammarby Sjöstad and Stockholm Royal Seaport neighbourhoods as eco-districts, where new developments are required to meet higher environmental standards.

4.2. San Francisco

The population of San Francisco is approximately 860,000. San Francisco has a mild climate, which results in a lower heating and cooling load compared to the other two cases. GHG emissions city-wide have decreased (see Table 2), primarily due increased renewable energy because of California's Renewables Portfolio Standard and the closure of two fossil fuel plants in San Francisco (San Francisco, 2013). San Francisco has had a Green Building Code since 2008 requiring energy efficient new and majorly retrofitted buildings linked to the LEED and

Table 2
Selected aspects of case study governance contexts .

	Local authority targets	Larger jurisdiction context	Indicators of progress	Key policies and programs
Stockholm	Fossil fuel free by 2030 for city operations and 2040 for the whole city Reduce per capita emissions to 2.3 tons CO_2eq/capita by 2020 Halve the energy use of the existing building stock by 2050 (from 1995 levels) (City of Stockholm, 2016)	The Swedish Building Code requires a high degree of efficiency and the EU has directed members to achieve near zero energy in new buildings by 2020 (Hermelink et al., 2013) Sweden's goals are to reduce GHG emissions 40% from 1990 by 2020 and no net GHG emissions by the year 2050	Stockholm's GHG emissions reduced approximately 56% between 1990 and 2016 (C40 Cities, 2017) 30% reduction (from 1995 levels) in energy use in existing building stock (City of Stockholm, 2016)	Local government and agencies are required to reduce energy use by 10% between 2016 and 2019 New buildings on city-owned land required to meet a high energy efficiency standard (max 55 kWh/m^2) Energy efficiency demonstration projects Eco-district development
San Francisco	100% renewables goal: by 2030, residential electricity is planned to come from renewable sources and 80% of commercial electricity use is planned to come from renewable sources (City of San Francisco, 2013)	Increased renewable energy because of California's Renewables Portfolio Standard (San Francisco, 2013) California building code targets: new residential buildings to be Zero Net Energy by 2020, commercial buildings in 2030 California Global Warming Solutions Act (2006): reduce GHG emissions to 1990 levels by 2020	San Francisco's GHG emissions city-wide decreased 14.5% between 1990 and 2010 (San Francisco, 2013) 7.9% reduction in energy use among commercial properties that regularly comply with the Benchmarking Ordinance (SF Environment, 2015)	San Francisco's Green Building Code San Francisco's Energy Benchmarking Ordinance for commercial buildings Renewable energy supply through CleanPowerSF Capacity building programs including Energy Upgrade and Energy Watch
London	GHG reduction target of 60% (below 1990 levels) by 2025 (Mayor of London, 2016) Zero carbon city by 2050 (Mayor of London, 2016) 25% of the heat and power used in London to come from local decentralized systems by 2025 (City of London, 2015)	UK Climate Change Act: reduce greenhouse gas emissions by at least 80% of 1990 levels by 2050 Reduced coal combustion in the UK (reduced GHG emissions for electricity) EU directive to achieve near zero energy in new buildings by 2020 UK Zero Carbon Homes target by 2016 (cancelled in 2015)	London's GHG emissions decreased 16% between 1990 and 2014 and per capita emissions estimated at 4.4 tonnes in 2014 (Mayor of London, 2017) Average energy efficiency savings 30–40% above national building code requirements since 2007 on large urban developments (City of London, 2015) Retrofits of 500,000 homes in London and 400 public sector buildings by 2014 (Mayor of London, 2015)	RE:FIT and RE:NEW GLA energy efficiency programs Energy Company Obligations for energy efficiency The London Plan energy requirements for large developments The London Green Fund

GreenPoint Rated green building rating systems. California is also increasing energy efficiency levels through the building code to meet Net Zero Energy targets. The City of San Francisco requires that buildings over 10,000 sq ft must benchmark their energy use and conduct an energy audit. Some private building energy efficiency retrofits are taking place due to the combined impact of San Francisco and California's energy efficiency policies and programs, including Energy Upgrade which connects homeowners with energy efficiency incentives offered by their local government and utilities and Energy Watch which offers energy efficiency services and financial incentives to businesses, contractors, and apartment building owners. In 2016, electricity customers in San Francisco began to be automatically transitioned to the municipally owned utility program CleanPowerSF, which sells customers electricity incorporating a higher percentage of renewable energy at the same cost as the electricity that they were previously sold from the investor-owned utility.

4.3. London

The Greater London Authority (GLA) has a population of about 8.6 million. While GHG reductions in London between 1990 and 2014 (see Table 2) can be partly attributed to building retrofits and changes in the transportation sector, much of these reductions are due to changes in energy supply, particularly reduced coal combustion nationally (Mayor of London, 2015). While heating and building efficiency have been key concerns, attention is also turning to the growing cooling load. Using planning tools, GLA sets both energy supply and efficiency requirements for large developments in London and also promotes the expansion of district heating using planning tools. Energy efficiency retrofits for existing buildings are promoted through a number of programs (see Table 2), which offer technical capacity and consulting services to building owners and managers. Other energy efficiency programs using loans or subsidies are also delivered by local boroughs and by energy companies and funded by various sources, including the national government. Decentralized and renewable energy development is also pursued by the boroughs. For example, the borough of Merton requires new developments to provide 10% of its energy use from on-site renewable energy generation (Merton Council, 2016). Renewable energy development is also being funded through community initiatives, including cooperatives like Brixton Energy.

5. Practices of decarbonization

This section examines the patterns emerging through decarbonization practices and analyses which aspects of urban materiality come to matter as carbon governance is translated into building-energy infrastructure. Drawing from across the cases, I identify five key patterns: (1) decision-making timeframes and decarbonization deadlines, (2) spatial solutions and tensions for building-energy decarbonization, (3) exceptional urban space for learning and overcoming cost-effectiveness, (4) responsibility for decarbonization and entrenched interests in energy supply, and (5) the struggle to retrofit the existing built environment.

5.1. Decision-making timeframes and decarbonization deadlines

The presence (or absence) of a long-term decarbonization frame influences the material shape of energy and building decisions made today. For example, the Greater London Authority mapped heat and energy demand for large urban developments while considering goals and predictions up to the year 2030. Since the study considered cost effectiveness and the characteristics of the broader electricity grid in addition to decarbonization goals, it found that "within that timeframe…gas-fired [combined heat and power plants]" for district energy made the most sense (Greater London Authority environment department employee, interview, Sept 8 2015). Natural gas powered district energy gained salience in London as a central plank in the GLA's low

carbon policies. More recently, work done by the GLA has recognized that when 2050 decarbonization goals are also considered, this new district energy network will need to transition away from natural gas again in the not too distant future. However, the material characteristics of a district energy system must be quite different in order for it to use natural or waste heat sources to replace natural gas, including different locations for pipes and different building design (Greater London Authority environmental department employee, interview, Sept 8 2015; London development industry representative, interview, Sept 15 2015). Summing up this dynamic, another research participant described the impact of timeframe on urban low carbon decision-making:

> "We've got a grid carbon emission factor. So when you do the math for a new flat, gas wins every time because it's about 40% less carbon intensity than you get from electricity. But that's only today. We know that we're involved in a massive, massive political consensus to reduce our grid carbon emissions factor. Surely we should be thinking about that. It's like…our left arm is planning for this glorious future and the right arm is going 'Let's pretend that's not happening'."
> (London development industry representative, interview, Sept 15 2015)

While natural gas might provide a marginal reduction in greenhouse gas emissions over the short term, in the long term natural gas expansion represents material entrenchment of fossil fuels that is incompatible with 2050 decarbonization goals. When working within a short-term frame, decarbonization actors identified different problems to solve compared to a long-term frame, which resulted in different building and energy infrastructure in practice.

Urban actors are starting to put deadlines on decarbonization (e.g. all new homes to be carbon neutral by 2016 in the UK, all new homes to be zero net energy by 2020 in California, or fossil fuel free by 2040 in Stockholm) in addition to more familiar incremental greenhouse gas emission reduction targets (e.g. 20% GHG reduction by 2020). Whether because a larger policy framework makes it seem inevitable or because decarbonization goals become normal for a jurisdiction, the adoption of specific timelines often allowed decarbonization actors to refocus the discussion on *how* to implement decarbonization rather than *when* to do it. For example, in California, one research participant described how setting big, bold energy efficiency targets for the state was about "saying this is where we think we need to go, let's figure out how to get there rather than spending our time on the goal setting part", which "has been extremely valuable" (City of San Francisco environment department official, interview, Apr 14, 2016). The same dynamic is taking place in Stockholm, where public housing companies understand that "you can't really say, no we aren't going to fulfill those [targets]. We have to…it's a fact" (Stockholm development industry representative, interview, Nov 23, 2015) and the discussion has turned to creating plans and measuring progress. Of course, the existence of a target linked to a timeline does not guarantee success. In the UK, the Zero Carbon Homes goal was abandoned right before the deadline despite an EU directive pushing the UK in the same direction. In addition, California is not going to meet its goal to retrofit half of all existing buildings to ZNE by 2030 (San Francisco consultant, interview, Apr 29, 2016).

Nonetheless, a sense of inevitability about decarbonization can be used to shape current urban buildings and energy infrastructure implementation. The Greater London Authority could use the UK's zero carbon homes goal policy framework as "an extra stick", for example, where they "could point to the direction of travel and say well you're going to have to get there anyway" (London consultant and former GLA employee, interview, Oct 5, 2015) to support the GLA's requirements for large urban developments to meet a slightly more ambitious trajectory. Temporal boundaries for decarbonization (not just marginal improvement) can be incorporated into an assumed trajectory for urban infrastructure development that decarbonization actors can leverage to shape current decision-making.

5.2. Spatial solutions and tensions for building-energy decarbonization

Across the case studies, the spatial approach to decarbonization took two formats: a district-oriented approach or self-sufficient building approach. In the district-oriented approach, chunks of the city are conceptually and materially linked together and made more efficient while being supplied by lower carbon energy sources. In London, for example, new developments are "obligated, if they're appropriate for district CHP, to go ahead with it" (London consultant and former GLA employee, interview, Oct 5, 2015). The thinking is that this new infrastructure would provide some flexibility for London to enable decarbonization. As one GLA employee described, the idea is to "get a heat network up and running and then you can look at supplying it in different ways with fuels… Whereas at the moment we don't even have that option…we're just tied into a gas grid and a power grid. At least it would give us a little bit of flexibility to transition at some point in the future" (Greater London Authority environment department employee, interview, Sept 8 2015). For this format, decarbonization actors stressed the importance of networks of new or refurbished infrastructure linking together buildings. Stockholm heating and electricity supply has been configured using a district energy approach for decades, but renewable fuels have gradually replaced fossil fuels in district heating, notwithstanding one large coal-fired heat and power plant remaining in Värtan (City of Stockholm, 2016). Stockholm has also concentrated decarbonization efforts on eco-districts, which is elaborated on in the next section. Cities like Stockholm have achieved some acclaim in urban circles for the degree of decarbonization enabled by district configurations and, as a result, other cities are copying the district approach.

When pursuing a building-oriented decarbonization format, decarbonization actors largely treat each building as an island in the effort to enhance each building's decarbonized self-sufficiency. For years, San Francisco has had a building code that has required developers to achieve a higher standard for energy efficiency and renewable energy than the statewide building code. In this approach, the building code is harnessed to try to decarbonize the city one new or majorly altered building at a time. Recently, building code updates have been reoriented to work towards achieving California's target for all new buildings to be Zero Net Energy (ZNE) by 2030. San Francisco stakeholders have been involved in discussions about "what a ZNE code actually looks like" particularly concerning how much solar electricity can be generated on-site to offset the building's energy use (San Francisco environmental NGO employee, interview, Apr 20, 2016). In a similar demonstration of a building-oriented approach, a planning rule was adopted by the London borough of Merton that stated that 10% of a new building's energy use must be produced using on-site renewable energy. The Merton Rule was influential and not only spread widely among other London boroughs, but was also adopted by the Greater London Authority (Merton Council, 2016). When buildings are targeted individually, each building is approached as a node and decarbonization actors design building-energy solutions to decarbonize that node.

There is some contestation within the decarbonization actor community about which format is better. People have criticized the self-sufficient buildings approach for a lack of interconnectivity between buildings and a perceived failure to capture the benefits of a systems approach to energy. For instance, one participant in the research highlighted the Merton Rule in London specifically:

> "I think one of the most damaging aspect or policy was something called the Merton rule whereby we looked at one building and said that building is going to be sustainable and then you'd spend money on making that building be self-sufficient where actually what you need – a more cost effective way of doing it was to have a community based approach."
> (London development industry representative, interview, Oct 1 2015)

This participant in the research argued that a focus on individual buildings overlooked the opportunities for district energy solutions, particularly from a cost perspective. Another critique is the unintended side effects of a building-by-building approach. A not-for-profit has expressed concern that the ZNE target in California could encourage sprawl "since it might be harder to get a…building to be ZNE in a city where you don't have space for on site renewables" (San Francisco environmental NGO employee, interview, Apr 20, 2016). On the other hand, the district approach has been critiqued as too narrow in focus, which causes it to miss other kinds of low carbon opportunities better suited to individual buildings (e.g. heat pumps) (London development industry representative, interview, Sept 15 2015; London development industry representative, interview, Sept 7 2015). Different decarbonization actors take different approaches and so both kinds of spatial solutions are present to some extent in the urban case studies.

5.3. Exceptional urban space for learning and overcoming cost-effectiveness

In some cases, spaces within a city are cordoned off as exceptional decarbonization zones. This is the case in Stockholm, where one decarbonization strategy has been to build particular neighbourhoods to very high green standards. The Royal Seaport is a large area of urban land undergoing brownfield redevelopment from port lands to mixed used/residential developments. The city owns the land, and places a number of environmental requirements into the development agreements, including meeting a high energy efficiency standard. In many ways, City of Stockholm decarbonization actors see the Royal Seaport as "a test bed for many new things which then should be generalized and put into ordinary projects" (City of Stockholm planning administration employee, interview, Nov 5, 2015). Decarbonization actors also position municipal buildings in San Francisco as exceptional space since publicly owned buildings must meet higher standards than the Green Building code, including LEED Gold certification. In San Francisco, the public mandate of the local government means that they are willing to spend money on more experimental technologies to achieve additional public good goals (in this case, decarbonization). In the case studies, exceptional spaces are used to facilitate learning and to build capacity in both the private and public sector, whether it is related to cutting-edge efficient building construction techniques or new institutional systems to track and enforce adherence to standards. The theory of change behind this approach draws on niche theory, which explores how learning happens in protected space and then scales up more broadly (Smith et al., 2010). That said, there are also concerns that the exceptional nature of these urban spaces makes the experiences incompatible with ordinary projects (Stockholm development industry representative, interview, Nov 24, 2015). Many low carbon solutions are often considered to be too expensive without the added support of a public mandate or high value urban real estate.

In addition to supporting learning, the exceptional nature of urban space provides a venue to overcome the tyranny of cost effectiveness in maintaining the status quo. In general across the three cases, urban decarbonization was pursued only as far as was 'cost effective' under a particular paradigm, usually using logics developed under fossil fuel entrenchment. For example, the measure of cost-effectiveness for building codes in California uses a complicated metric called TDV (Time Dependent Valuation) that effectively prioritizes natural gas:

> "The purpose of the TDV metric…is to try to account for the time value, particularly of electricity use. But because of the way they came up with the numbers and just because of the difference in cost between electricity and gas, the electricity TDV values are much higher than the gas TDV values. Ranging from 3:1 at low use hours to like 100:1 at high use, peak summer hours for electricity. And because of that, if you're comparing an electric appliance to a baseline of a gas appliance, it does not look good."
> (San Francisco environmental NGO employee, interview, Apr 20 2016)

Appliances like gas furnaces can be powered by electricity rather than fossil fuels in California to transition the energy system and reduce greenhouse gas emissions. However, as the previous quote explains, the metric used to measure cost-effectiveness works against this transition since the metric favours natural gas. Because the development of the metric was based on assumptions about a fossil fuel based energy system, cost-effectiveness is now linked to the perpetuation of fossil fuels. As this demonstrates, the fossil fuel entrenchment of the status quo can be perpetuated through requirements to meet 'cost effectiveness'.

One way decarbonization actors have addressed the tyranny of cost effectiveness has been by leveraging premium urban land to enable the first (and therefore more expensive) explorations into cutting edge decarbonization in practice. Many of these initiatives are concentrated in downtown neighbourhoods. In Stockholm, developers want to participate in the Royal Seaport development despite having to meet higher environmental standards than the rest of the city (and country) because it is high value urban land. A similar dynamic takes place in London: "Because London is such a premium area to want to develop buildings, developers would sometimes go the extra mile or they would actually see the logic of [energy and carbon requirements]" (London consultant and former GLA employee, interview, Oct 5, 2015). The GLA is able to require higher energy standards and participation in lower carbon energy generation schemes because of the high value of the real estate in large, central urban developments. Beyond central commercial areas, the city can be more broadly seen as an exceptional space compared to national or international context. Again, this exceptionality relates to disparities in real estate value: "In Stockholm it's really expensive to buy something also so I mean the builders will also make money even if they have sharper requirements on those buildings. Maybe not in smaller cities…but in Stockholm we don't have that problem…." (City of Stockholm politician, interview, Nov 27, 2015). The experiences in cities may shift the market more broadly. In California, one participant noted that the adoption of 'reach' codes with higher energy efficiency standards "helps shift the market more and more in that direction which then enables future code additions at state level to increase" (San Francisco environmental NGO employee, interview, Apr 20, 2016). Capacity building in the exceptional spaces within and across urban areas can enable decarbonization in broader jurisdictions.

5.4. Responsibility for decarbonization and entrenched interests in energy supply

One participant in the research memorably drew my attention to the "elephants and mosquitos" of decarbonization (City of Stockholm planning administration employee, interview, Nov 5, 2015). The elephants are large steps towards decarbonization (e.g. shutting down a coal plant) and the mosquitos are the small steps toward decarbonization (e.g. door to door home energy auditing). The participant has found that decarbonization actors often struggle to address the elephants and, as a result, spend too much time focusing on the mosquitos. Powerful entrenched fossil fuel interests are often the reason it is difficult to address the elephants of decarbonization. In Stockholm, multiple research participants identified the 'elephant' as a single combined heat and power (CHP) plant in Värtan in the northeast of Stockholm that is fired by coal and biofuel. This plant is the single largest source of greenhouse gas emissions in Stockholm (City of Stockholm, 2010). Its continued operation has been a political issue in Stockholm for many years (Rutherford, 2014) and continues to be a source of contention:

> "Fortum wants to run it for 10-15 years in the future because it is very cheap for them to use it. But the politicians said…that in 2020 they want that to be closed. But Fortum said "No, we can't do that". So I will say now that the negotiations [to close it down] are landing

in somewhere 2025 to 2028."
(City of Stockholm environment administration employee, interview, Nov 10 2015)

The coal plant was quasi-privatized between 1998 and 2002, but the City of Stockholm retains a 50% influence through half the seats on the board (Rutherford, 2014). In recent years, the company that owns the plant, Fortum Värme, has increased the proportion of fuel from biofuel, but municipal planning documents describe it as technically difficult to fully convert the plant to biofuels (City of Stockholm, 2012). As a result, the coal plant becomes an immovable object that must be navigated around in order to achieve urban decarbonization goals:

> "Further reductions will occur when coal use at the Värtaverket power plant is cut in half during the coming 4–5 years. After that, we cannot count on significant reductions within district heating. Therefore, it is important that the City works ambitiously with energy efficiency throughout its property portfolio, and that traffic becomes more and more independent from fossil fuels."
> (City of Stockholm, 2012)

Carbon largely becomes the problem of other actors (including individual citizens) to compensate for the continued pollution of the coal fired CHP plant in the pursuit of decarbonization goals. As participants in the research made clear, many feel it is unfair that a company continues to operate infrastructure that produces so much carbon pollution while the rest of the city is asked to decarbonize.

However, this is not to say that entrenched interests in energy supply cannot be overcome. After over 10 years of contestation in San Francisco, a transition is taking place so that the municipally owned utility is now the default electricity service provider (although the private utility still owns wires, billing and delivery). Decarbonization actors pursued this transition in order to work towards achieving a 100% renewable electricity by 2030 target. Rather than a simple issue of who will supply electricity, it has been a political and ideological issue that has been on the ballot multiple times and featured contentious negotiations (San Francisco environmental NGO employee, interview, Apr 19, 2016). Nonetheless, CleanPowerSF began supplying customers in May 2016.

5.5. The struggle to retrofit the existing built environment

Decarbonization actors from across the three case studies struggle to retrofit the existing built environment to improve energy efficiency and to introduce low(er) carbon energy supply. While there has been substantial progress in setting high standards for new buildings, urban actors struggled to address the challenges posed by the existing built environment. The materiality of the city seemed to resist change. This dynamic was repeated whether it referenced district energy ("When you walk around London and you think how would you put an 8 m pipe down the road. We had enough trouble just putting in cable TV and that's a tiny wire" [London development industry representative, interview, Sept 7 2015]); building retrofits and cultural values ("[London is] a very dense city, with a lot of historical buildings which you can't touch" [London development industry representative, interview, Sept 15 2015]); building ownership structures (joint ownership in Stockholm where you own 10% of the building as an association member and technically rent your flat from the association where "people that are living in the house are elected to take care of everything during the year. And this is just ordinary people…They don't know so much about energy efficiency" [City of Stockholm environment administration employee, interview, Nov 28, 2015]); or commercial buildings ("You try telling the developer 'Hey, you're forced to retrofit your building' – see how far you get" [San Francisco consultant, interview, Apr 29, 2016). These examples are just a few of the ways that material politics limit the application of low carbon retrofit solutions in the existing built form.

There are two main dynamics at play in the struggle to retrofit the existing urban built environment. First, who should pay? Various approaches to financial loans and incentives have been developed to try to catalyze retrofits. Many efforts have targeted sectors of society described as people 'able to pay', such as loans to homeowners or information provision about cost-effective energy retrofits for large commercial buildings. The PACE program in San Francisco is a good example:

> "Everyone recognizes the need to retrofit existing buildings for more efficiency and renewables and it seemed that there was a collective realization that capital to pay for these improvements was something that we need to focus on. PACE stands for property assessed clean energy… private property owners could basically opt in to use the program to fund energy efficiency and renewable energy projects on their properties and pay it back through their property taxes. It was a novel way to address a lot of the traditional barriers to provide capital for these types of projects."
> (City of San Francisco environment department employee, interview, Apr 12 2016)

In a few cases, efforts have targeted disadvantaged or marginalized actors, such as grants to citizens in environmental justice neighbourhoods to install solar panels in San Francisco or support for retrofits in the UK to counteract 'fuel poverty' where a household income is too low to keep a home warm at a reasonable cost. In general across the case studies, retrofits for decarbonization are approached as a material improvement to private property that, while supported by society, largely remains the financial responsibility of building owners.

Second, who must decarbonize? Many building-energy decarbonization initiatives are focused on retrofitting private homes. Some initiatives have started to target large commercial buildings (e.g. San Francisco's energy benchmarking and auditing program). Many initiatives target decarbonizing energy supply, but they encounter difficulties overcoming entrenched interests. Participants in the research recognized there were also significant challenges reaching large sectors of society. In particular, participants identified buildings that are rented to tenants and small businesses as especially problematic sectors that are only minimally targeted. As one research participant in London explained, one "sector that we're not really doing any work with…is the small medium sized enterprises – very difficult group to interact with" (London borough (Croydon) employee, interview, Oct 5, 2015). Furthermore, other than energy generation facilities, industry was almost universally absent as a target for decarbonization. By and large, the retrofit of the existing built environment has failed to reach large sectors of society to enable change.

6. Implications for decarbonization pathways

People are reconfiguring the urban materiality of Stockholm, London and San Francisco as they work to achieve low carbon transformations. As carbon governance unfolds, particular bits of building-energy infrastructure begin to matter, including residential building envelopes, exceptionally low carbon neighbourhoods, and heat demand location. This process of making particular things matter is a political process since it highlights some aspects of building-energy infrastructure and not others in ways that represent particular interests (Rutherford, 2018). This section analyzes how what is being made to matter during the implementation of carbon governance impacts whether or not cities are on pathways toward decarbonization. I have grouped these implications around the themes of time, space and agency, which is one way to open up considerations of relational materiality.

Time is a key factor influencing how urban decarbonization actors pursue building-energy transformations. In particular, different understandings of time impact whether actors can effect change that has the potential to lead to decarbonization. A short-term frame creates a

different problem to be solved (e.g. relative decrease in greenhouse gas emissions) than a long-term decarbonization frame (e.g. energy transition), which brings different energy generation configurations to the fore as solutions. Depending on the timeframe, different material configurations appear to make sense as solutions, but these configurations are not necessarily reversible and have limited flexibility once they are implemented. New socio-material obduracies are created through building-energy infrastructure investments. This dynamic has implications for decarbonization because, as is clear in the London example, shorter timeframes can drive practices that support the more efficient use of fossil fuels rather than overcoming the entrenchment of fossil fuels to achieve transformation. In sum, when actors filter carbon governances through short timeframes, immediate greenhouse gas emission reduction can come to matter the most. However, the socio-material configurations of these solutions may set up a trajectory toward more efficient fossil fuel use rather than overcoming carbon lock-in.

Furthermore, the evidence from the three cases also shows how targets that put a deadline on decarbonization can become normalized, which can allow decarbonization actors to shift the discussion to tangible acts of implementation and contestation. As others have found, targets nest together scientific and political elements to create normative pressure, including "affirm[ing] what is legitimate to reach, indicat[ing] the direction to be taken and provid[ing] the common language to translate priorities and programmes into a policy outcome" (Morseletto et al., 2016). The findings show that targets are not always achieved, but they also show that urban decarbonization actors are actively leveraging these deadlines; some urban actors reinforced the inevitability of decarbonization in order to facilitate the implementation of carbon governance practices in current infrastructure development. Similarly, work on the sociology of expectations has found that actors actively reference what is possible in the future, which influences current technological development (van Lente, 2012). Urban actors are reinforcing expectations about the inevitability of future decarbonization in order to encourage or require the implementation of decarbonization today.

Space is also a key factor influencing how urban decarbonization actors pursue building-energy transformations. In particular, spatial solutions for urban decarbonization have normative and performative power. Decarbonization actors are trying to enable the performance of decarbonization by following emerging configurations of low carbon districts or building-oriented decarbonization. However, decarbonization actors sometimes positioned the spatial configuration itself as the solution to decarbonization (e.g. district energy is the solution) while other critical material elements are de-emphasized (e.g. natural gas fuel now, but it will transition to renewables 'later'). This approach depoliticizes the materiality of decarbonization configurations to represent tangible, physical elements as interchangeable without acknowledging the ways that investment in particular configurations represents the establishment of power relations. Different spatial solutions for decarbonization foreground different socio-material solutions, which has implications for whether or not successful decarbonization transitions are achieved.

In addition, decarbonization actors felt they were required to justify carbon governance in relation to cost-effectiveness, despite the fact that cost-effectiveness metrics are often deeply intertwined with fossil fuel entrenchment. As a result, cost-effectiveness can limit the broad application of low carbon transformation. However, local government decarbonization actors leveraged premium urban space to set higher decarbonization standards since the (perceived and actual) marginal cost of achieving those standards was more than offset by the gains. This exceptional decarbonization space in the city was spatially bounded and often in central commercial neighbourhoods because the flow of high levels of development capital was particularly essential to the strategy. Other literatures have also identified the potential of exceptional urban space as a venue for experimental governance, such as the literature on living labs (Governance of Urban Sustainability Transitions and Urban Europe, 2017; Voytenko et al., 2016). Scholars have also noted the significant issues with viewing urban space as an experiment by reducing it to "a *tabula rasa* on which new technologies, transitional strategies, and other approaches can be tried and tested, and subsequently rolled out across wider scales" (Caprotti, 2014). Despite the promising role of these niches, they bring up troubling questions about whether there is a growing dynamic of "accumulation by decarbonization" (Bumpus and Liverman, 2008) where privileged central urban spaces for the professional class and multinational commercial sector are disproportionately benefitting from decarbonization. If practices appropriate for exceptional urban space cannot make the leap to universal application, decarbonization may be another force of eco-gentrification with concerning implications for uneven development. This finding connects to critical approaches to urban green redevelopment that have pointed out the "intensification of environmental and economic inequalities in the geographies of eco-urbanism" (Caprotti, 2014), contested the flattening of complex socio-natures for green building retrofit certification (Knuth, 2015), critiqued the rise of "luxury ecologies" or urban environmental developments benefitting the professional class and related businesses (Cohen, 2017), and questioned configurations of moral and political responsibilities for urban climate action (Fuller, 2017)

Finally, agency is a key factor influencing how urban decarbonization actors pursue building-energy transformations. An emerging pattern in decarbonization practice is the individualization of decarbonization responsibility. Despite the large carbon impact of fossil fuel energy supply, the strength of entrenched interests makes many decarbonization efforts targeting this sector into drawn out negotiations (see also Blanchet (2015) and Monstadt and Wolff (2015)). When this dynamic takes place, utilities argue for the right to continue operating and collecting profit from high carbon assets while everyone else around them decarbonizes. Powerful entrenched interests make some aspects of building-energy infrastructure immovable (e.g. privately owned coal plant) and some movable (e.g. residential building fabric). Carbon then becomes a problem for homeowners and commercial building owners, usually alongside decarbonization of local government operations. The individualization of low carbon responsibility echoes the individualization of environmental subjectivity more broadly under neoliberalism (Brand, 2007). The unfairness of the dynamic is nonetheless clear; carbon becomes a problem for individuals to solve through their investments and choices immediately, while actors with powerful control over structural levers of fossil fuel entrenchment wait as long as possible to act. Of course, emerging patterns of carbon governance are complex and the emphasis on individual responsibility runs alongside a logic of 'leading by example', where local governments decarbonize their own operations and assets.

Decarbonization governance is also coalescing around patterns related to who should be responsible for paying for decarbonization. In particular, many building-energy decarbonization initiatives have framed carbon as a problem that should be solved through investments in private buildings and energy infrastructure. Within this frame, decarbonization actors have struggled with the implementation of retrofits to achieve decarbonization since the materiality of the city and related vested interests resist change. Furthermore, it was widely acknowledged by research participants that large sections of society are not being reached in efforts to decarbonize the existing built environment, including rented residential buildings and small and medium enterprises, which is a troubling challenge for urban actors committed to decarbonization.

Overall, there are important implications for the directions these cities are headed. When decarbonization actors adopt a long-term decarbonization framework (as opposed to short term logic of marginal improvement), it can drive building-energy infrastructure investments that may overcome fossil fuels. New urban space is moving towards decarbonization despite variations in the spatial configurations and

specific imaginaries about what that might mean for urban futures (e.g. zero carbon, net zero energy etc.). In particular, decarbonization actors' efforts to harness the exceptional nature of the urban, particularly related to real estate value for new developments, show some potential to overcome the tyranny of cost-effectiveness in maintaining the status quo. However, upgrades to existing buildings are limited in scope. The socio-material obduracy of the built environment has required decarbonization actors to develop finely detailed policy customization based on building type, ownership, and willingness/ability to pay, and yet participants in the research still identified significant struggle across the three urban case studies. The material politics of building-energy retrofit for decarbonization are proving particularly troublesome and retrofit of the existing built environment is proceeding too slowly to meet long-term decarbonization goals. Finally, there has been some success in decarbonizing energy supply, although the interests entrenched in the socio-material energy system are difficult for decarbonization actors to tackle.

This paper has also identified a number of concerns based on patterns of decarbonization practice. In particular, I argue that it is unjust to overemphasize individual responsibility for decarbonization as opposed to overcoming fossil fuel interests and achieving structural change in building and energy systems. Furthermore, large swaths of society (particularly the rental market, small and medium enterprises, and industry) remain hard to reach in efforts to transform the existing built environment. Finally, uneven low carbon development and retrofit through spatially bounded demonstration sites or eco-districts threatens to drive eco-gentrification. It is necessary to find pathways from exceptional urban space to ordinary applications.

7. Conclusion

Urban low carbon transitions suggest a substantial re-ordering of urban infrastructure. However, research so far has largely painted a picture of incremental ambitions that have faced struggles in implementation, which means there is a critical need to engage with the material implications of low carbon practices. Here, I have focused on three urban case studies where actors are aiming for transformation in order to provide a novel deepening of our understanding of implemented urban carbon governance. By applying a material politics approach, I examined patterns in what is being made to matter through the translation of carbon governance into building-energy infrastructure. Decarbonization pathways will differ across the case studies, influenced by factors such as different climates, governance contexts, and existing built environments, but this paper has examined commonalities across the cases in order to generate conceptual insights into urban decarbonization practices.

Emerging patterns in urban decarbonization practices carry implications for whether or not cities are on trajectories toward decarbonization. The paper found that a short-term decision making timeline (e.g. 2020 or 2030) encourages action that incrementally reduces greenhouse gas emissions without fundamentally overcoming carbon lock-in, but that the long-term timeline (e.g. 2050) creates different problems and solutions that can engender decarbonization trajectories. The paper also found that different socio-material solutions are foregrounded when actors focus on different spatial solutions for decarbonization, which has implications for whether or not successful decarbonization trajectories are achieved. Furthermore, actors are harnessing exceptional urban space to overcome the tyranny of cost-effectiveness in maintaining carbon lock-in, although the use of high value urban land for this process raises concerning implications for justice and uneven development. In addition, there is a pattern of individualization of responsibility for decarbonization, which allows powerful agents in industry to continue to operate high carbon assets and maintain political and technological carbon lock-in. Finally, material politics limit the application of low carbon retrofit solutions in the existing built form, which will significantly impede urban decarbonization efforts given that the majority of urban buildings in the cases are expected to remain standing in 2050.

A material politics approach to urban decarbonization offers a way to conceptually capture the messy, materially embedded and contested nature of infrastructure transformations. Decarbonization is recast as an inherently political and on-going process of assembling together various human and non-human elements. In general, acknowledging infrastructure as messy and contested can make it seem difficult to change. Instead, this application of a material politics approach demonstrated how opening up our understanding of decarbonization pathways beyond technological choices actually reveals many potential leverage points in urban systems to spur decarbonization.

Decarbonization experiences in cities vary and it is important to broadly consider stories of transformation. This paper has specifically focused on wealthy cities in industrialized nations that bear the bulk of the responsibility for historical greenhouse gas emissions and it is critical that future research also theorizes and empirically examines low carbon development in the urban global South. Future research can also delve more deeply into the patterns identified in this paper. In particular, research can continue to explore the tension between leveraging the urban as exceptional space and the dynamics of eco-gentrification, the political economies of energy utilities in the context of low-carbon transitions, and ways to overcome the obduracy of the built environment to achieve energy efficiency retrofits.

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